COMPLETION, CALIBRATION AND TESTING OF AN APPARATUS FOR MEASURING THE THERMAL TRANSMITTANCE OF FABRICS

BY

J. A SMITH

COMPLETION, CALIBRATION AND TESTING OF AN APPARATUS FOR MEASURING THE THERMAL TRANSMITTANCE OF FABRICS

A Thesis presented to the Faculty of the Lowell Textile Institute as a partial requirement for the degree of Master of Science in Textile Engineering

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INTRODUCTION

Since very early times man has worn clothing to protect him from extremes in temperature. In the cold climates skins of animals were used, while in the tropics such fibers as cotton and flax were woven into fabrics. Although it has always been known that different fabrics and fibers were warmer or colder when used as garments, it was not until 1890 that actual study of the thermal transmission of wearing apparel was undertaken to any great extent. Since this time many apparatuses for the measurement of thermal transmission or insulation have been developed. Some of these followed closely devices already in use for the measurement of the thermal transmission of metals or other solids. The types that have been used in the study of textiles may be divided into three groups: (1) two plate method as exemplified by the M.I.T. Heat Transmission Apparatus[1]; (2) cooling method as used by Priestman in 1921; and (3) constant temperature method, the best example of which is the apparatus at the National Bureau of Standards[2]. This last type would appear to be

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1. Rayon Textile Monthly, Sept.-Oct. 1940
2. R. S. Cleveland, An Improved Apparatus For Measuring The Thermal Transmission Of Textiles, NBS Vol.19, No. 6, Dec. 1937

the one in most general use today. It is the method used by all the cooperating laboratories in the investigation conducted by the American Society for Testing Materials to determine a standard test for evaluation of the thermal - transmission characteristics of textile fabrics[1].

The apparatus to be described is an adaptation of the constant temperature, flat plate method and is similar in principle to the National Bureau of Standards machine developed by Cleveland. Several new ideas have been incorporated which tend to give simplicity of testing without any loss of accuracy. Any desired temperature difference between the hot plate and testing chamber is automatically maintained by means of photoelectric tubes and amplifiers.

1. G. Winston & S. Baker, Measurement of The Thermal Transmission of Textile Fabrics, ASTM Bul. No. 162, Dec. 1949

PURPOSE

The purpose of this thesis is: (1) to complete the design and construction of an apparatus for measuring the thermal transmission of textile fabrics; (2) to calibrate the apparatus so that any desired temperature difference between the hot plate and cold junction may be set on the dial and automatically maintained; and (3) to conduct tests to determine the accuracy and reproducibility of results.

THEORY

Conduction, convection, and radiation are the three main processes by which heat is transferred from one region to another. Conduction is the transfer of heat by direct contact between two bodies or action between molecules within a body. In the case of fabrics the heat energy passes by contact first from the heat source to the fibers in contact with it and then from fiber to fiber until it passes completely through the thickness of the fabric. There is also some conduction by the air entrapped within the fabric. Convection is the transfer of heat energy by means of the motion of matter. It refers to motions occurring in liquids and gases and not the random molecular motions occurring in all bodies. The convection concerned with here is that of the entrapped air within a fabric. It will be set in motion by the change in density due to the heat from the heat source and the fibers. The amount of radiation is determined by the nature of the emitter and its temperature. It is the transfer of heat by radiant energy. All bodies emit and absorb radiant energy continually. In the case of fabrics

the radiant energy may be transmitted through the material or conducted heat may be radiated from the surface of the fabric.

In this work no attempt has been made to separate the different methods of heat transfer, therefore, all three are being measured. The heat source is a flat copper plate. The fabric is placed on this plate and the amount of electrical energy necessary to keep the plate at a constant temperature is measured. The air above the fabric is also kept at a constant temperature but at some level below that of the copper plate. Thus, the heat transferred by the fabric is equal to the electrical energy, converted into heat energy, supplied during the time of the test. In order that all the heat loss from the copper plate shall take place through the fabric, the guard-ring principle has been used. The heat source is surrounded by guard units which are kept at the same temperature as the central plate, and thus prevent heat loss either laterally or downward.

Automatic controls have been installed on the apparatus in order to shorten the time of each test and also to eliminate the constant attention of an operator.

The automatic controls necessitate an on and off supply of current to keep the temperature of the heat source constant because the exact continuous current necessary for a given fabric cannot be predicted before testing and its determination would unduly prolong a test. Since nichrome heating coils are used for the apparatus, the current supply for the central heating plate is on a high - low basis. That is, instead of turning off when the plate has reached the desired temperature, the current is turned to a lower value that is equal to half the high current. This is done to partly eliminate the effects of the temperature coefficient of resistance of the nichrome. It also gives less variation in temperature and a slower change that prevents the temperature of the central coil from overshooting or undershooting its mark after the high current is either turned on or off by the relays.

The electrical input in watts to the central plate may be measured by the I^2R method, the EI method or by using a watt-hour meter to measure energy input. For the purpose of this work, the watt-hour meter may be eliminated because direct current is used and no watt-hour meter is available in the proper volt range. The I^2R

method is most satisfactory when the nichrome heating coil is at a constant temperature, then no correction for temperature has to be made. As tests were conducted with the central plate temperature ranging from 20° C. to 45° C., this method of measuring the wattage was not satisfactory. The EI method gives the most satisfactory results with the least chance of error. The main source of error in this method is the variation in voltage supply. This has been reduced as far as possible by connecting the central plate heating coil direct to the battery terminals.

Some thought must be given to the proper instant for starting and stopping a test and the length of time of each test. As the current is on a high - low basis, the best overall average would be obtained by starting and stopping each test at the same point in a cycle. In order to obtain regular cycles, the high and low currents should be so set that they are each on one-half the total time of the test. This same reasoning holds true for the guard units but, as the power input to these heating coils is not measured, the on-off current is satisfactory. Theoretically, the total time of a test may be of any desirable duration. However, due to the cycling of the

current supply, the longer the time of the test the better chance of averaging out some of the uncertainties. During any test there will be some moisture driven off from the fabric and the heat necessary to vaporize this moisture is measured. Thus, an error is introduced here that will vary for fabrics of different moisture content. From this standpoint a short test would be desirable so that all fabrics would be tested at close to their normal moisture content.

The coefficient of heat transfer as measured by this apparatus is computed in calories/second/meter^2/degree centigrade. It is the quantity of heat supplied to the central plate per second divided by the difference in temperature between the copper plate and the test chamber and the area of the plate. The electrical energy supplied to the central plate is measured by:

$$W = I_H E_H t + I_L E_L (T-t)$$

W = joules

I_H = high current in amperes

E_H = voltage corresponding to I_H

I_L = low current in amperes

E_L = voltage corresponding to I_L

T = total time of test

t = time high current is on

The numerical relation between heat and mechanical energy, which is implied by the first law of thermodynamics, was measured by Joule about 1845. This work showed that one calorie is equivalent to 4.186 joules. Thus, the heat in calories supplied to the copper plate is:

$$H = \frac{W}{4.186}$$

The coefficient of heat transfer is then computed as:

$$K = \frac{W}{(4.186)\ A\ \theta}$$

A = area of central plate in square meters

θ = temperature difference between central plate and test chamber

It will be noted that no mention is made concerning the linear distance between the two sides of the material. This is normally taken into account when measuring thermal conductivity of metals. However, as the true effective thickness of fabrics is indeterminable, this value has not been used.

The standard formula for thermal conduction is:

$$q = \frac{k\ A\ (t_1 - t_2)}{s}$$

q = heat transfer

k = thermal conductivity

A = cross sectional area

$t_1 - t_2$ = temperature difference

s = distance between measuring points

This shows that the heat transfer is inversely proportional to the thickness of a specimen. In testing good conductors such as metals, this fact holds true but, in measuring such things as textiles, other factors enter into the picture. Textiles are poor conductors due to the air entrapped in them. It has been found that the heat loss through a fabric is greater than through an equal thickness of air, conduction through the actual fibers being a contributing factor[1]. Rees also pointed out that for fabrics of thickness greater than 100 mils, the equivalent air thickness is less than the fabric thickness by about 20 per cent at 100 mils fabric thickness, and about 40 per cent at 400 mils fabric thickness. Thus, one might not expect the thermal transmission of fabrics to be inversely proportional to thickness.

1. W. H. Rees, J. Textile Institute, Aug. 1941

In computing the coefficient of heat transfer the formula used would indicate that the actual temperature gradient would have no effect. Actually, this might not be true as conduction, convection and radiation are being measured together. At higher temperatures the radiation and convection effects may be much greater than the effect of conduction. Under these conditions the coefficient of heat transfer will tend to increase.

APPARATUS

The measuring apparatus and electrical circuits are the same as described in a previous thesis[1], with additions and modifications as described in the following sections. Also see figures 1 and 2.

Heating Circuits

The central plate heating coil was disconnected from the common 40 volt DC line and a 40 volt DC line run direct from the battery room to the central plate. This was done to eliminate the interference of the three guard units which caused the central plate current to vary whenever they were turned on or off. A blank prong on the six prong plug in the testing chamber was used to connect the central plate with the 40 volt line.

Amplification Circuit

A great deal of trouble was experienced at the start of the calibration with the relays failing to operate. In order to eliminate this, a series of changes were made in the amplification circuit. The heaters for

1. L.T.I. Thesis No. , 1950, An Apparatus For Measuring The Thermal Transmission Of Fabrics

the two 6C5 tubes were taken from the 6 volt DC line and connected to a 6.3 volt AC transformer. This prevented any change in operating characteristics due to battery failure and made the heaters independent of the other circuits.

The resistances in the grid circuits of the 6C5 tubes were changed from .5 megohms to 1 megohm in order to increase the grid bias. As the grid bias was still low, the adjustable 5M resistance in this circuit was removed and the connection made direct to the 0 volt line. A voltage divider between the 120 and 0 volt lines was then used and a 75 ohm adjustable resistance connected to the cathodes in order to give the proper grid bias. This eliminated the 6 volt DC line to the cathodes.

In order to make the system more sensitive to changes in the spotlight galvanometer, the photoelectric cells were moved away from the light about one-half inch and their ends overlapped. Thus, when the spotlight changes only a small degree in its arc, it can move from the sensitive element of one photoelectric tube to the other.

The box containing the galvanometer, amplifier

system and photoelectric tubes was supported at each corner from an overhead beam by means of four springs in order to eliminate vibrations reaching the galvanometer.

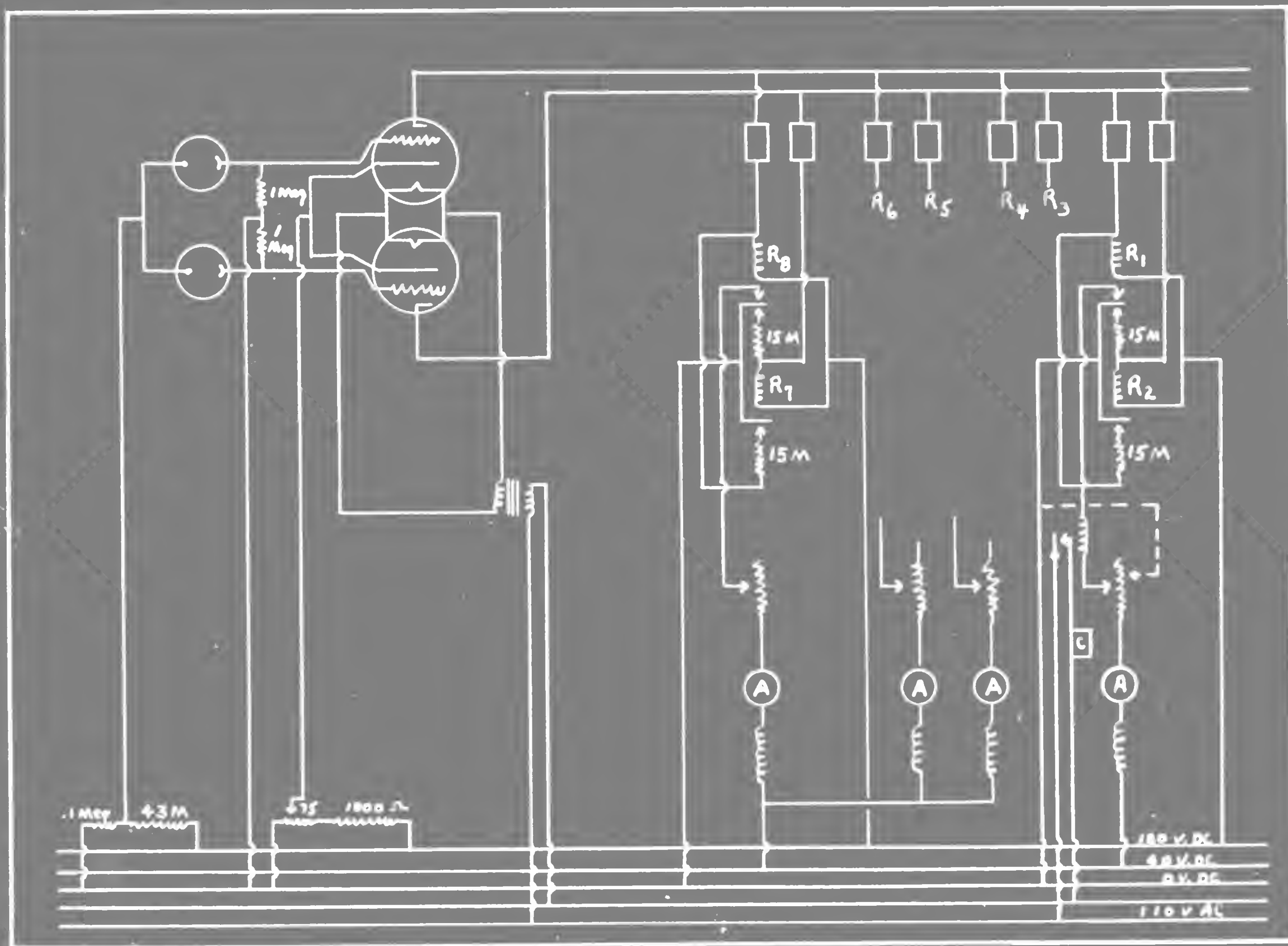
All the connections in the amplifying circuit and relays were resoldered to give a good contact.

The following equipment was installed:

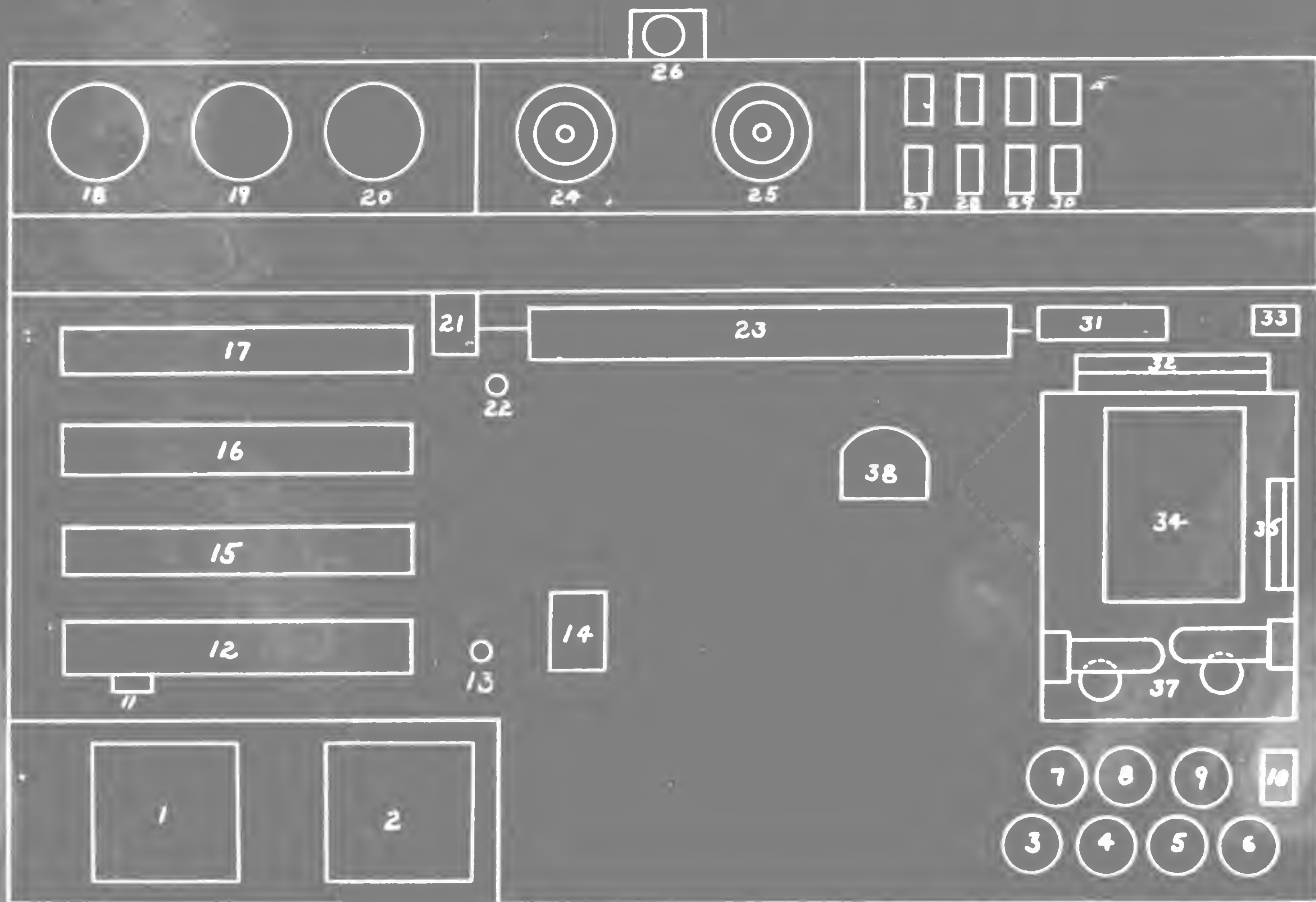
1. Two 5000 ohm relays in the shelf coil circuit
2. A 454 ohm rheostat in the shelf coil circuit
3. An ammeter in each guard unit heating circuit
4. A relay in the high current circuit of the central plate heating coil to turn an electric clock on or off with this current
5. A 110-120 volt 60 cycle clock
6. A 0-6 ohm rheostat in the thermovoltage cancellation circuit for the central plate

The refrigeration unit was overhauled and refilled with SO_2 but it became inoperative after only a

few tests were run. Therefore, the majority of the tests were run with the cold junction at room temperature. An attempt was made to keep this at 21° C. but it was not constant. On warm days the room temperature was as high as 27° C.



ELECTRICAL CIRCUITS
FIGURE I



SCHEMATIC DRAWING OF APPARATUS
FIGURE II

Identification of Figure II

1 Voltmeter across central plate heating coil
2 Ammeter in central plate heating coil circuit
3 Switch - 110 volts AC - for electric clock
4 Switch - 40 volts DC - for guard unit heating coils
5 Switch - 110 volts AC - for synchronous motor
6 Switch - 110 volts AC - for 6.3 volt transformer #10
7 Switch - 120 volts DC - for holding current
8 Switch - 110 volts AC - for 6.3 volt transformer #33
9 Switch - 40 volts DC - for central plate heating coil
10 Transformer - 110 volts - 6.3 volts - for galvanometer light
11 Low current contact in central plate heating coil circuit
12 Rheostat in central plate heating coil circuit
13 Switch for low current in central plate heating coil circuit
14 Relay in central plate heating coil circuit for electric clock
15 Rheostat in top guard ring heating coil circuit
16 Rheostat in bottom guard ring heating coil circuit
17 Rheostat in shelf heating coil circuit
18 Ammeter in shelf heating coil circuit
19 Ammeter in bottom guard ring heating coil circuit
20 Ammeter in top guard ring heating coil circuit
21 Synchronous motor - 110 volts AC - 1 RPM
22 Switch for thermovoltage cancellation circuit
23 Rotary switch for thermocouple circuits and relays
24 Rheostat in thermovoltage cancellation circuit
25 Temperature rheostat in thermovoltage cancellation circuit
26 Electric clock for high current in central plate heating coil circuit
27 Relays in shelf heating coil circuit
28 Relays in bottom guard ring heating coil circuit
29 Relays in top guard ring heating coil circuit
30 Relays in central plate heating coil circuit
31 Battery - 1.5 volts - in thermovoltage cancellation circuit
32 Resistor - 1000 Ω - in cathode circuit of 6C5 tubes
33 Transformer - 110 volts - 6.3 volts - for heating circuits of 6C5 tubes
34 Spotlight galvanometer
35 Resistor - 75 Ω variable - in cathode circuit of 6C5 tubes
36 Photoelectric tubes - Citron 1C
37 Amplifier tubes - 6C5

CALIBRATION

A sensitive thermometer was placed on the central plate and the bulb was covered with putty. As the early stages of the calibration were accomplished while the compressor was still operating, the testing cabinet was brought to 4° C. and the coils turned on and allowed to heat to the desired temperature. See page 27 for operating instructions. The 10000 ohm resistor in the central plate heating coil circuit was set so that the thermovoltage cancellation current was 0.8 milliampere. This current was such that the 0-6 ohm regulator could be calibrated in differences of temperature between the hot plate and cold junction ranging from 15° C. to 40° C.

The initial calibration showed a variation of ± 1° C. for any particular setting of the temperature rheostat, that is, the temperature difference would be 1° C. over the setting before the heating coil would be turned off and 1° C. below the setting before the heating coil came on again. In order to make the apparatus more sensitive to temperature changes, the photoelectric tubes were moved away from the galvanometer lamp locating them at

a greater radius from the mirror. Thus, the same temperature change now would cause the light to move farther across the photoelectric tubes. The ends of the tubes were overlapped to cut down the dead space between them. The light now moves from the cathode of one tube to the cathode of the other without any intervening space. With these changes made, the temperature setting was much more sensitive. The greatest variation now amounts to ± 0.2° C. With the testing box kept at a constant temperature, the present galvanometer should be accurate enough for normal testing. However, if at a later date it is found a more accurate temperature control is necessary, a more sensitive galvanometer could be used with the present circuits.

Throughout the calibration of the central plate the temperature of the top guard unit was also noted. This stayed within 1° C. of the central plate. It was always slightly lower due to the difference in location of the thermometer and the thermocouple leads. No attempt was made to measure the actual temperature of the bottom guard unit or shelf coil as these were enclosed in the box.

The settings above 20° should be checked again as soon as the testing chamber can be brought close to

4° C. These settings have not been recalibrated since the refinements were made. The temperature of the central plate should not be raised above 45° C. making the 20° setting the maximum possible when the testing chamber is at room temperature. However, the 25, 30, 35 and 40 degree settings are close to the corresponding scale division and should only have to be changed slightly, if at all. It is desirable to do all the calibrating with the thermovoltage cancellation current at 0.2 milliampere so that the use of only one scale will be necessary for a change in temperature. Table I shows a series of readings taken at both the 15 and 20 degree settings. These readings were at 5 minute intervals and show that the average for an hour is in error less than 0.2% of the desired temperature difference. These readings were taken with the testing box at room temperature. It will be noted that the room temperature varied during the time the results were taken. Without this variation in testing box temperature, there is a possibility the error will be even less than 0.1%.

TESTING

The test samples were cut in 12-inch squares in order to cover the central plate and top guard ring unit with a small allowance outside the guard unit. Table II gives a description of the fabrics used along with necessary details, such as weight, thickness, and permeability. In conducting a test, the specimen was placed on the central plate in a smooth, flat condition, without tension. The identification tag was always placed in the lower right hand corner of the testing box. The apparatus was turned on as described in the Operating Instructions. For the first hour the central plate heating coil rheostat was set at 0.7 ampere and each of the guard unit rheostats set at 1.0 ampere in order to heat the apparatus quickly. After about one hour, the units started turning off, and the desired testing currents were set--see Table III. This table should be used to obtain approximate high and low currents. The object is to select these currents so that the high current will be on approximately half the total time of the test. When the galvanometer remained in approximately the central position for a complete cycle of

the rotary switch, the apparatus had reached equilibrium and the test was begun. The start was either at the beginning or end of a high current cycle for the central plate heating coil. In order to best average the test, the stopping point was also at the same part of the high current cycle. It was found to be simpler to have the electric clock set at exactly 12-00-00 and to start the test when the high current turned on. The total time of the test was measured by a wrist watch with a sweep second hand. The only readings necessary for a test are the time of starting and stopping, the time the high current is on, the temperature rheostat, and the high and low currents of the central plate heating coil. For most fabrics, a total time of 3 hours is satisfactory for a single test. The coefficient of heat transfer is computed as shown on page 29 using Tables IV and V.

OPERATING INSTRUCTIONS

1. See that battery room voltmeter reads at least 120 volts with 135 volts preferred.
2. Turn on trickle charge for batteries.
3. Turn on refrigerator.
4. Plug in four leads to test control board.
5. Set thermocouple compensating current at 0.2 milliampere.
6. Set temperature rheostat at desired differential.
7. Turn on switches 4, 5, 6, 7, 8, and 9.
8. Place specimen on central plate without tension and in a smooth condition.
9. Set central plate current at 0.7 ampere and guard units at 1.0 ampere each.
10. When all heating coils are up to temperature, set currents to those desired for test.
11. When spotlight remains in approximately the central position for a complete cycle of the rotary switch, the apparatus is ready to commence a test.
12. Start test by turning on switch 3, observing time the high current to central plate turns on, and observing

electric clock reading.

13. Run test for desired length of time. Stop by observing time high current to central plate turns on and electric clock reading.

14. Calculate coefficient of heat transfer as shown in the sample calculation on page 29.

SAMPLE CALCULATION

$$K = \frac{I_H E_H t + I_L E_L (T - t)}{4.186\ A\ \theta\ T}$$

Symbol	Quantity	Units
K	. . . coefficient of heat transfer . .	cal/sec/m^2/$^\circ$C
I_H	. . . high current to central plate. .	amperes
I_L	. . . low current to central plate . .	amperes
E_H	. . . voltage corresponding to I_H. . .	volts
E_L	. . . voltage corresponding to I_L. . .	volts
t	. . . time I_H is on during test . . .	seconds
T	. . . time of duration of test	seconds
A	. . . area of central plate	meters^2
θ	. . . temperature gradient	$^\circ$C
4.186	. . number of joules in 1 calorie .	

Fabric #4

Temperature rheostat	20° C
High current	.35 amp.
Low current	.18 amp.
Test ended	14-56-13
Test started	10-54-47
T	14486 seconds
t	7060 seconds
T - t	7426 seconds

From Table IV

$I = .35 \quad IE = 1.51$

$I = .18 \quad IE = 0.3834$

From Table V

$\theta = 20$

$4.186\ A\theta = 0.582$

$$K = \frac{(1.51)(7060) + (0.3834)(7426)}{(0.582)(14486)} = 1.59 \text{ cal/sec/m}^2/^\circ\text{C}$$

TABLE I

Temperature Recordings of Central Plate and Testing Box

Time Minutes	Temperatures in ^{o}C					
	Dial at 15^{o} C			Dial at 20^{o}		
	Cold Junction	Central Plate	Differ-ence	Cold Junction	Central Plate	Differ-ence
00	25.9	40.7	14.8	24.8	44.8	20.0
05	25.8	40.8	15.0	24.5	44.3	19.8
10	25.6	40.6	15.0	24.5	44.2	19.7
15	25.5	40.5	15.0	24.8	45.0	20.2
20	25.2	40.2	15.0	24.9	44.9	20.0
25	25.5	40.6	15.1	25.0	45.0	20.0
30	25.5	40.6	15.1	25.0	45.0	20.0
35	25.3	40.3	15.0	25.2	45.4	20.2
40	25.4	40.4	15.0	25.1	45.3	20.2
45	25.8	40.9	15.1	25.0	45.2	20.2
50	25.4	40.6	15.2	25.0	45.0	20.0
55	25.8	40.6	14.8	24.5	44.8	20.2
60	25.5	40.5	15.0	24.8	45.0	20.0
		Total	195.1		Total	260.5
		Average	15.008		Average	20.04

TABLE II

Identification of Fabrics Used in This Work

Fabric	Description	Thickness[a] Inches	Ounces per Yard	Apparent Density #/ft^3	Permeability[b] $ft^3/min/ft^2$
1	Cotton sheeting	.0075	3.25	36.0	52.5
2	Tropical worsted	.0154	6.30	34.1	80.0
3	Cotton twill	.0197	8.0	33.6	12.2
4	Wool dress goods	.0238	6.1	21.2	126.8
5	Wool double cloth	.1034	23.5	19.1	38.2
6	Double loop frieze Wool pile - Cotton back	.2514	15.6	5.16	60.0
7	Alpaca pile - Cotton back	.2530	13.2	4.3	29.3
8	Dynel pile - Cotton back	.5352	23.1	3.59	75
9	Dynel pile - Dynel back	.6696	21.4	2.66	185

a - 1 - 5 in accordance with ASTM standards
6 - 9 with zero pressure

b - Gurley permeometer

TABLE III

Current Settings for a Temperature Gradient of 20° C

Approximate Fabric Thickness Inches	Estimated Heat Transfer	Current Settings - Amperes				
		Central Plate		Top Guard Unit	Bottom Guard Unit	Shelf Guard Unit
		High	Low			
0.0 - 0.03	1.50 - 2.10	0.35	0.18	0.70	0.60	0.60
0.03 - 0.15	1.00 - 1.50	0.30	0.15	0.60	0.60	0.60
0.15 - 0.40	0.70 - 1.00	0.25	0.12	0.60	0.60	0.60
0.40 - 0.70	0.0 - 0.70	0.25	--	0.60	0.60	0.60

TABLE IV

Amperes and Volts for Central Plate Heating Coil

I	E	IE
.12	1.45	.174
.15	1.90	.285
.18	2.13	.383
.20	2.50	.500
.25	3.10	.775
.28	3.50	.980
.30	3.70	1.11
.35	4.31	1.51
.40	4.98	1.99
.45	5.55	2.50
.50	6.20	3.10

TABLE V

Constants Used in Computations

θ	$4.186\ A\theta$
15	.437
20	.582
25	.727
30	.871
35	1.020
40	1.164

TABLE VI

Data for Table VII

Fabric	e	Amperes High	Amperes Low	Time Start	Time Stop	T	t	T - t	K
1	20	.40	.20	11-33-07	13-20-42	6455	1628	4827	2.09
					14-27-02	3980	1843	2137	2.04
2	20	.40	.20	11-23-10	13-20-01	7011	2095	4916	1.62
					14-25-40	10950	3971	6979	1.80
					15-27-15	14645	5703	8942	1.86
					16-26-44	18214	7589	10625	1.92
3	15	.30	.15	12-18-38	13-09-39	9661	5735	3929	1.78
					16-26-06	14248	8317	5931	1.76
	20	.35	.18	09-33-00	13-22-29	13769	9147	4622	1.94
	30	.45	.25	13-46-30	14-47-18	3648	2026	1622	2.12
					15-47-53	7283	4409	2874	2.04
					16-46-35	10805	6377	4428	2.04
				10-47-45	11-49-30	3705	2591	1114	2.15
					12-50-10	7345	4815	2530	2.17
					13-45-40	10075	6755	3320	2.14
	35	.50	.30	11-01-06	12-02-50	3764	2054	1710	2.15
					14-09-20	11294	5627	5667	2.06
					14-59-42	14316	7382	6934	2.10
					16-00-22	17966	9685	8281	2.14

Fabric	e	Amperes High	Amperes Low	Time Start	Time Stop	T	t	T - t	K
4	15	.25	.12	10-59-35	12-50-08	7833	3341	4492	.984
					13-45-12	11017	6298	4719	1.18
					14-22-15	14020	9049	4971	1.28
					14-52-44	15249	10158	5091	1.21
		.30	.15	09-42-33	12-26-41	9848	3486	6362	1.32
					13-21-54	13221	4713	8508	1.32
	20	.35	.18	09-30-48	10-20-58	3010	1467	1533	1.60
					11-24-30	6822	3181	3641	1.56
					13-23-23	13955	6816	7139	1.62
				11-32-33	13-31-35	7146	2835	4311	1.53
					14-30-11	10658	3837	6821	1.42
					15-29-50	14237	4903	9334	1.38
				10-29-46	11-31-37	3711	1774	1937	1.58
					13-00-06	9020	3540	5480	1.42
					13-38-45	11339	4788	6551	1.47
					14-28-35	14329	6167	8162	1.49
				10-41-10	14-23-56	13366	5388	7978	1.44
				10-54-47	14-56-13	14486	7060	7426	1.59
	35	.50	.30	12-10-06	15-22-52	10366	3608	6758	1.77

Fabric	θ	Amperes High	Amperes Low	Time Start	Time Stop	T	t	T - t	K
5	20	.40	.20	10-27-34	11-25-22	3468	1178	2290	1.70
					12-25-18	7064	1807	5257	1.50
					13-23-26	10552	2393	8159	1.44
					14-27-40	14406	3082	11324	1.40
					16-35-20	22066	4461	17605	1.38
6	20	.25	-	10-24-47	11-29-26	3879	2377	-	.817
					12-32-55	7688	5393	-	.937
					14-43-04	15497	11463	-	.988
7	20	.28	.15	10-56-19	13-05-35	7756	2766	4990	.915
					14-00-05	11071	5058	6013	1.02
					14-58-16	14516	6151	8365	.995
					15-33-31	16632	6267	10365	.990
8	20	.25	-	12-22-26	14-10-56	6510	3075	-	.628
					15-35-50	11004	5223	-	.631
					16-29-00	14194	6505	-	.613
9	20	.24	.12	10-53-24	13-45-00	10296	234	10062	.320

TABLE VII

Coefficient of Heat Transfer of Nine Fabrics

Fabric	Temperature Gradients				
	15	20	25	30	35
1		2.04			
2		1.92			
3	1.76	1.94		2.09	2.14
4	1.32	1.50			1.77
5		1.38			
6		.868			
7		.990			
8		.615			
9		.320			

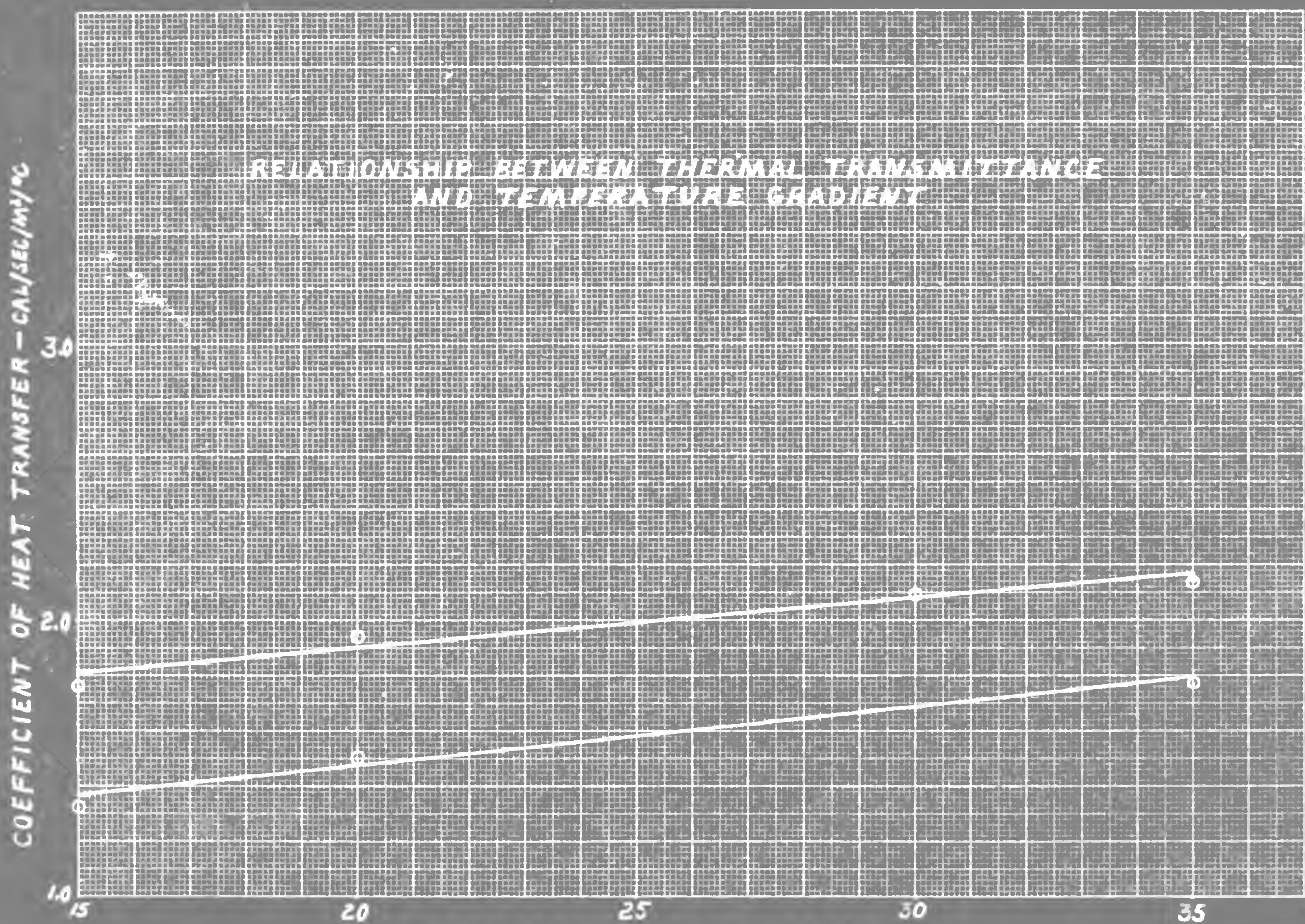

RELATIONSHIP BETWEEN THERMAL TRANSMITTANCE
AND TEMPERATURE GRADIENT
COEFFICIENT OF HEAT TRANSFER — CAL/SEC/M²/°C
3.0
2.0
1.0
15
20
25
30
35
TEMPERATURE DIFFERENCE — °C

FIGURE III

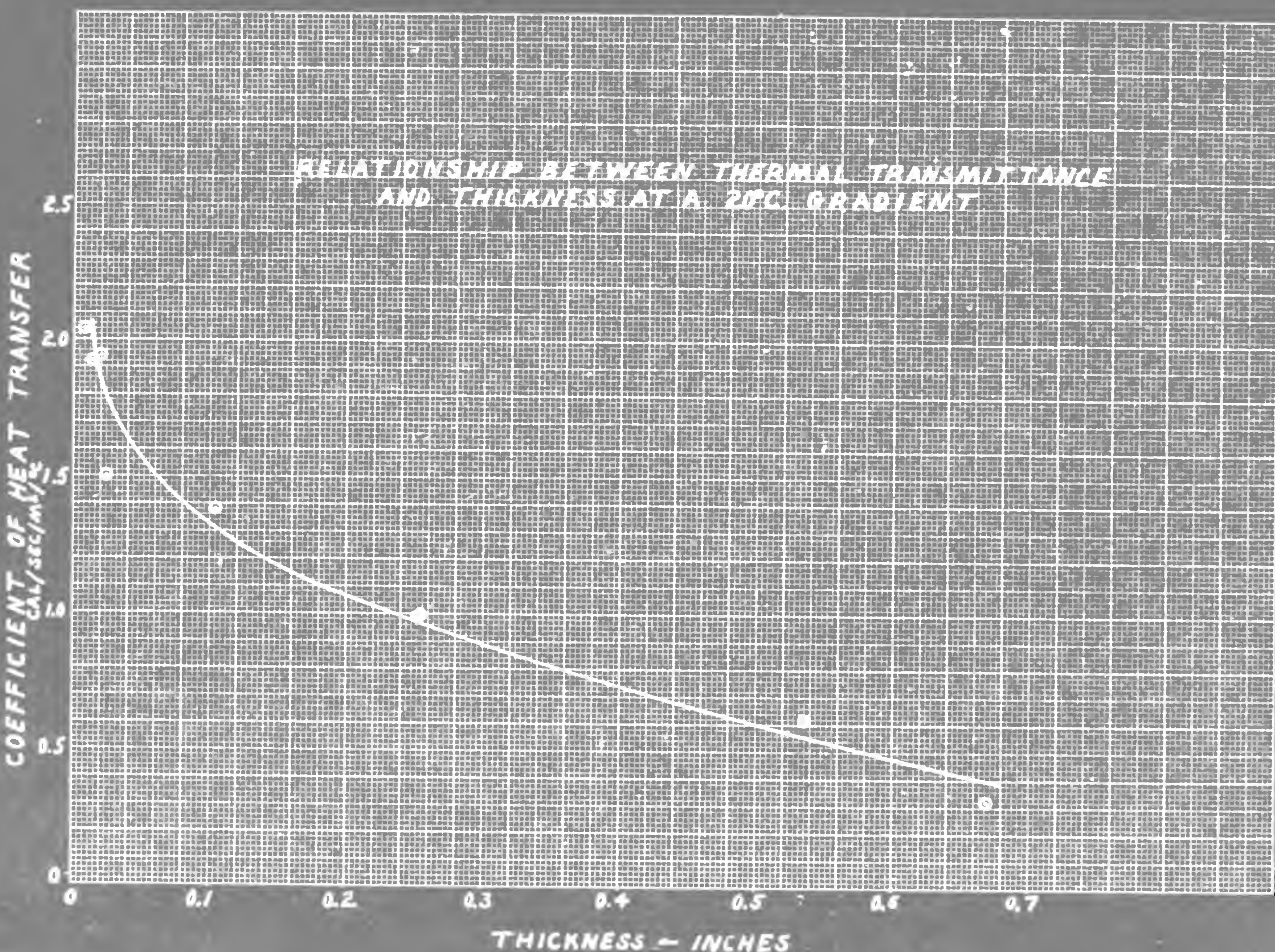

RELATIONSHIP BETWEEN THERMAL TRANSMITTANCE
AND THICKNESS AT A 20°C. GRADIENT
COEFFICIENT OF HEAT TRANSFER
CAL/SEC/M²/°C
2.5
2.0
1.5
1.0
0.5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
THICKNESS — INCHES

FIGURE IV

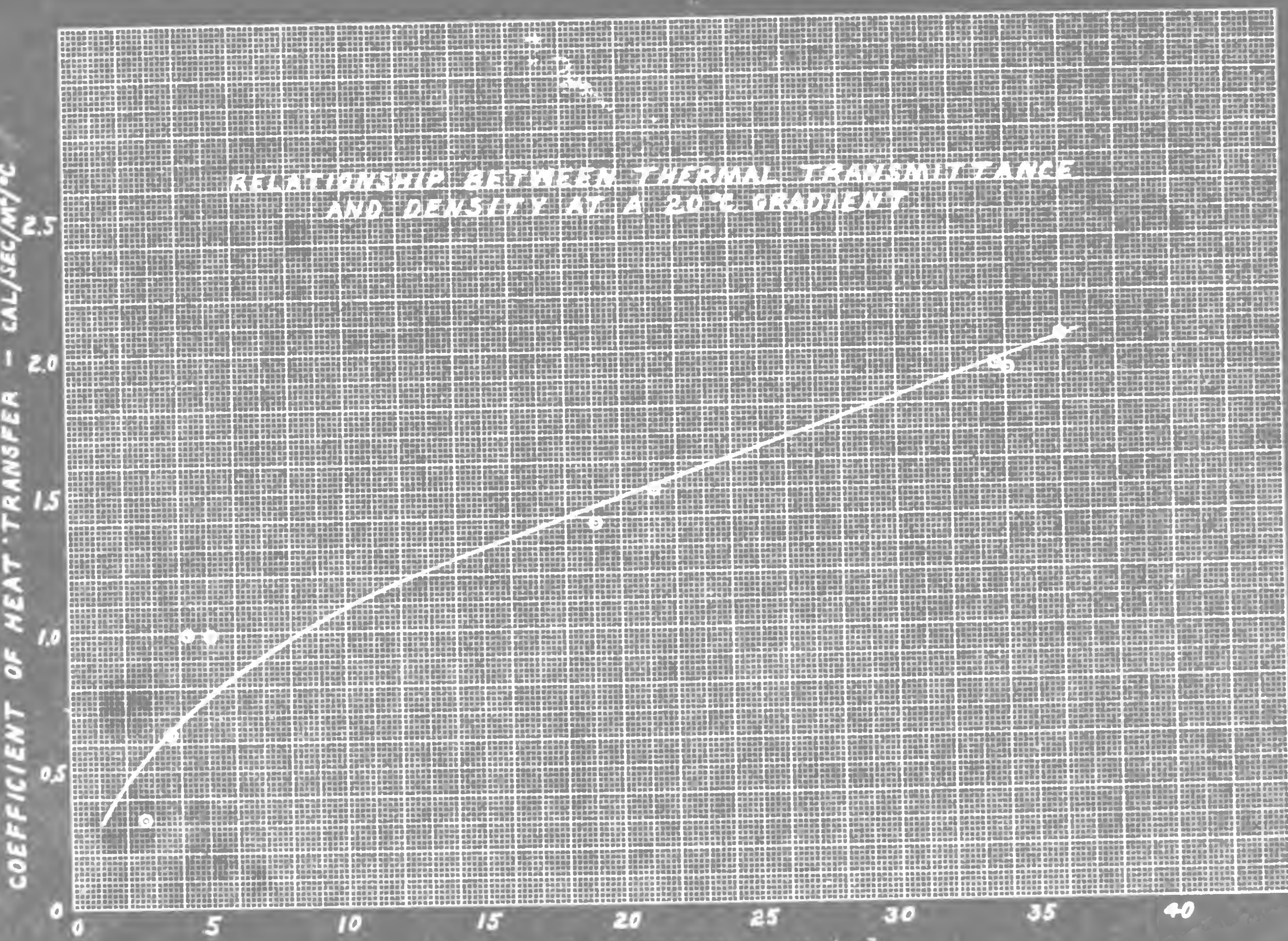

RELATIONSHIP BETWEEN THERMAL TRANSMITTANCE
AND DENSITY AT A 20°C GRADIENT
COEFFICIENT OF HEAT TRANSFER - CAL/SEC/M²/°C
0
0.5
1.0
1.5
2.0
2.5
0
5
10
15
20
25
30
35
40
APPARENT DENSITY — lbs/ft³

FIGURE V

DISCUSSION AND CONCLUSIONS

The automatic temperature controls have proved very accurate. Table I shows a series of readings taken at both the fifteen and twenty degree centigrade differentials. The average for one hour at the fifteen degree setting was in error only 0.008 degree, while the twenty degree setting showed an error of 0.04 for an hour. The largest deviation in any case was 0.3 degree centigrade for the twenty degree setting. This amounts to only 1.5% which, in this case, is not significant. Even if a complete test were conducted with a temperature error of 0.3 degree centigrade, the computed coefficient of heat transfer would only be changed by 0.02. This is well within the reproducibility of the apparatus. One must remember that these results were obtained without a constant temperature in the test chamber. When a new refrigeration unit is installed, the temperature control should be even more accurate. It should be noted that any change in the testing cabinet temperature requires a corresponding change in the central plate temperature in order to keep the same temperature gradient. The apparatus makes this compensation automatically, but one must remember

that the heat input to the central plate is different when it is being kept at a constant temperature then when its temperature must be raised or lowered. It is also believed the temperature control can be improved by painting the central plate and top guard unit with a black lacquer. This will not give a better control for any one test, but will give better temperature control over a period of time due to a more constant emissivity of the hot plate.

The coefficient of heat transfer was determined for all the fabrics at the twenty degree differential. Time did not permit tests for all the fabrics at the other settings but tests were run at the fifteen degree gradient for fabrics 3 and 4. Before the refrigeration unit became inoperative, tests were run at the thirty-five degree gradient for fabrics 3 and 4 and also at thirty degrees for fabric 3. The results obtained in all of the tests are shown in Table IV.

The relationship between the coefficient of heat transfer and temperature gradient is shown on Figure III. The coefficient actually increases somewhat with an increase in temperature differential. It means that more heat is transmitted per degree centigrade for a greater temperature

gradient. This behavior may be due to increased radiation loss but may also be affected by convection of the air above the fabric. One might assume that the procedure of reporting the coefficient of heat transfer as calories/second/meter^2/degree centigrade is not justified. However, this does reduce the coefficient to an approximate common basis for different temperature gradients. However, in reporting any results, the temperature differential used should be stated. This would be necessary for any attempt at correlation between different laboratories or apparatuses. For use at Lowell Textile Institute, it is believed the best results will be obtained if a standard temperature differential is chosen and all work done with this gradient for a comparison of results.

As stated previously, theoretically, the length of time of a test may be any desired interval as long as it covers complete cycles of the high and low currents. However, in actual practice, it has been found that a four-hour test gives the best results for fabrics tested at a twenty degree differential. That is, the four-hour tests seem to give the best reproducibility. However, when the suggestions for future work are carried through, it may be found

that a much shorter test will give accurate results. An attempt should be made to reduce the testing time as much as possible in order to allow more tests to be conducted in any one work day. A positive statement can not be made concerning the length of time to conduct a test. The data in Table VI is presented in such a manner that the coefficient of heat transfer is computed from the original starting time in each case. That is, the three-hour result includes the total time of three hours and not just the hour time interval between the two and three hour readings. No definite trend exists in any of the results. In some cases the coefficient of heat transfer increases with each hour of testing while in others it decreases. In still other instances, the coefficient increases and then decreases during a period of four hours, while for other fabrics, the results show first a decrease and then an increase. Even for a single fabric the coefficient will increase during a test in one instance and decrease in another. No one period of all the tests can be eliminated to give better results. That is, the first hour results does not show a wide variation from the remaining hours, nor does it coincide with a coefficient of heat transfer computed for a two, three, or four hour test.

A plot of the coefficient of heat transfer versus thickness of fabric is shown in Figure IV. Figure V shows a plot of coefficient of heat transfer versus apparent density. Apparent density was computed from the weight per yard and thickness as shown in Table II. These graphs show that the best correlation is between thickness of fabrics and heat transfer. This same fact has been brought out by previous studies[1]. For actual use, however, the thickness of fabrics will vary with compression, wear or location in a garment. Thus, a cotton blanket may appear just as warm as a wool blanket when tested in a new condition but, after six months' use, the effective thickness of the cotton will be much less, due to the higher resilience of the wool. This testing was conducted without pressure on top of the fabric but, for such things as cold weather boot insulation, a pressure per square inch equal to that exerted by a man's weight must be used to give results that are closer to the actual values found in use. Pressure on the fabric could be produced by a metal plate with a thermocouple to give the temperature difference between the hot and cold plates.

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1. G. Winston & S. Baker, Measurement of The Thermal Transmission of Textile Fabrics, ASTM Bul. No. 162, Dec. 1949

The coefficient of heat transfer of 1.50, as shown in Table VII for fabric 4, was obtained from an average of five four-hour tests. The results varied from 1.38 to 1.62 as shown in Table VI. The variations may be due to the fact that the temperature of the testing cabinet was not controlled, or to variations in voltage supplied to the central plate heating coil. If these are not the cause, a large number of tests will be required for testing small differences in materials. However, it is believed that with the testing cabinet kept at a constant temperature and a constant voltage supply, the reproducibility should be such that small variations in thermal transmittance of fabrics can be measured with a single test on each fabric.

SUGGESTIONS FOR FUTURE WORK

1. After a new refrigeration unit has been installed, check the 25, 30, 35, and 40 degree settings of the temperature rheostat for any slight inaccuracies.
2. Test many more fabrics of varying thicknesses, to determine the accuracy of the curves shown on Figures III and IV.
3. Paint central plate with a black lacquer to give it approximately the emissivity of the human body. This will also prevent changes in emissivity due to oxidation of the copper plate.
4. Test fabrics that are alike except for color, to determine effect of color on thermal transmission.
5. Test different layers of the same fabric.
6. Attach a fan inside the test cabinet to determine the effect of wind velocity on the fabrics already tested.
7. A more constant voltage supply or use of a watt-hour meter should give better reproducibility of results.

Thesis 15586
S584 Smith
Completion, calibration and testing of an apparatus for measuring the thermal transmittance of fabrics